

## Claims

- [c1] 1. A method for controlling a hybrid powertrain system for an automotive vehicle operated by a user, the system having an engine, an electric machine that performs as a motor in one mode of operation and performs as a generator in another mode of operation, a battery connected to the electric machine, and a generator configured to receive mechanical power from the engine and to present electrical power to at least one of the electric machine and the battery, and at least one of the engine and the electric machine establish a power source for providing power to vehicle traction wheels, the method comprising the steps of:
- determining a first power state of the hybrid powertrain system;
  - limiting electrical power generated by the generator to the minimum of the rated power limit of the generator and the first power state, when the first power state is greater than zero; and
  - limiting the electrical power generated by the generator to zero, and limiting the power limit of the electric machine during generating to a first operating condition of the hybrid powertrain system, when the first power state

is less than or equal to zero, to provide over-charge protection to the battery.

[c2] 2. The method set forth in claim 1 wherein the first power state includes the sum of the actual mechanical output power of the electric machine, the actual power loss of the electric machine, the actual total power consumed by the auxiliary loads, and the battery charge power limit; and the first operating condition includes the negative of the sum of the actual power loss of the electric machine, the actual total power consumed by the auxiliary loads, and the battery charge power limit

[c3] 3. The method set forth in claim 2 wherein a battery charge current limit to provide both over-current and over-voltage protection to the battery is equal to the minimum of the rated battery charge current limit and a battery charge current limit predetermined by testing for avoiding battery over-voltage, and the battery charge power limit is equal to the minimum of the rated battery charge power limit and the product of battery voltage and the battery charge current limit.

[c4] 4. The method set forth in claim 1 further, when engine start is of higher priority to the user than drive performance, including the steps of:

limiting the power limit of the electric machine during motoring to the minimum of the rated power limit of the electric machine, and the negative of a second operating condition of the hybrid powertrain system, when the second operating condition is less than zero; determining when a third operating condition of the hybrid powertrain system is less than zero, when the second operating condition is equal to or greater than zero; limiting the auxiliary loads to the minimum power for maintaining the vehicle operation, and limiting the power limit of the electric machine during motoring to the minimum of the rated power limit of the electric machine and the negative of the third operating condition, when the third operating condition is less than zero; and adjusting an engine start strategy to provide earlier starting of the engine, when both the second and the third operating conditions are equal to or greater than zero, to provide over-discharge protection to the battery.

- [c5] 5. The method set forth in claim 4, wherein the second operating condition includes the sum of the discharge power limit of the battery, the actual total power consumed by the auxiliary loads, the negative of the actual electrical power output of the generator, and the actual power loss of the electric machine; and

the third operating condition includes the sum of the discharge power limit of the battery, the minimum auxiliary power for maintaining vehicle operation, the negative of the actual electrical power output of the generator, and the actual power loss of the electric machine.

[c6] 6. The method set forth in claim 5 wherein a battery discharge current limit to provide both over discharge current and under-voltage protection for the battery is equal to the maximum of the rated battery discharge current limit and a battery discharge current limit predetermined by testing for avoiding battery under-voltage, and the discharge power limit of the battery to provide over-discharge protection to the battery equals the maximum of the rated battery discharge power limit and the product of the battery voltage and the battery discharge current limit.

[c7] 7. The method set forth in claim 1 further, when drive performance is of higher priority to the user than engine start, including the steps of:  
limiting the electrical power of the generator during motoring to the maximum of the negative of the rated power limit of the generator, and a fourth operating condition of the hybrid powertrain system, when the fourth operating condition is less than zero;  
determining when a fifth operating condition of the hy-

brid powertrain system is less than zero, when the fourth operating condition is equal to or greater than zero; limiting the actual total power consumed by the auxiliary loads to the minimum auxiliary power requested, and limiting the electrical power of the generator during motoring to the maximum of the negative of the rated power limit of the generator and the fifth operating condition, when the fifth operating condition is less than zero; and adjusting an engine start strategy to provide earlier starting of the engine, when the both the fourth and the fifth operating conditions are equal to or greater than zero, to provide over-discharge protection to the battery.

- [c8] 8. The method set forth in claim 7, wherein the fourth operating condition includes the sum of the discharge power limit of the battery, the actual total power consumed by the auxiliary loads, the actual mechanical output power of the electric machine, and the actual power loss of the electric machine; and the fifth operating condition includes the sum of the discharge power limit of the battery, the minimum auxiliary power requested, the actual mechanical output power of the electric machine, and the actual power loss of the electric machine.

[c9] 9. A system for controlling a hybrid powertrain for an automotive vehicle operated by a user, the system comprising:

- an engine;
- an electric machine that performs as a motor in one mode of operation and performs as a generator in another mode of operation;
- a battery connected to the electric machine, wherein at least one of the engine and the electric machine establish a power source for providing power to vehicle traction wheels;
- a generator configured to receive mechanical power from the engine and to present electrical power to at least one of the electric machine and the battery; and
- a controller configured to:
  - determine a first power state of the hybrid powertrain system;
  - limit electrical power generated by the generator to the minimum of the rated power limit of the generator and the first power state, when the first power state is greater than zero; and
  - limit the electrical power generated by the generator to zero, and limit the power limit of the electric machine during generating to a first operating condition of the hybrid powertrain system, when the first power state is

less than or equal to zero, to provide over-charge protection to the battery.

- [c10] 10. The system set forth in claim 9, wherein the first power state includes the sum of the actual mechanical output power of the electric machine, the actual power loss of the electric machine, the actual total power consumed by the auxiliary loads, and the battery charge power limit; and the first operating condition includes the negative of the sum of the actual power loss of the electric machine, the actual total power consumed by the auxiliary loads, and the battery charge power limit.
- [c11] 11. The system set forth in claim 10 wherein a battery charge current limit to provide both over-current and over-voltage protection to the battery is equal to the minimum of the rated battery charge current limit and a battery charge current limit predetermined by testing for avoiding battery over-voltage, and the battery charge power limit is equal to the minimum of the rated battery charge power limit and the product of battery voltage and the battery charge current limit.
- [c12] 12. The system set forth in claim 9, wherein, when engine start is of higher priority to the user than drive performance, the controller is further configured to:

limit the power limit of the electric machine during motoring to the minimum of the rated power limit of the electric machine, and the negative of a second operating condition of the hybrid powertrain system, when the second operating condition is less than zero; determine when a third operating condition of the hybrid powertrain system is less than zero, when the second operating condition is equal to or greater than zero; limit the auxiliary loads to the minimum power for maintaining the vehicle operation, and limit the power limit of the electric machine during motoring to the minimum of the rated power limit of the electric machine and the negative of the third operating condition, when the third operating condition is less than zero; and adjust an engine start strategy to provide earlier starting of the engine, when both the second and the third operating conditions are equal to or greater than zero, to provide over-discharge protection to the battery.

- [c13] 13. The system set forth in claim 12, wherein the second operating condition includes the sum of the discharge power limit of the battery, the actual total power consumed by the auxiliary loads, the negative of the actual electrical power output of the generator, and the actual power loss of the electric machine; and the third operating condition includes the sum of the



discharge power limit of the battery, the minimum auxiliary power for maintaining vehicle operation, the negative of the actual electrical power output of the generator, and the actual power loss of the electric machine.

[c14] 14. The system set forth in claim 13 wherein a battery discharge current limit to provide both over discharge current and under-voltage protection for the battery is equal to the maximum of the rated battery discharge current limit and a battery discharge current limit predetermined by testing for avoiding battery under-voltage, and the discharge power limit of the battery to provide over-discharge protection to the battery equals the maximum of the rated battery discharge power limit and the product of the battery voltage and the battery discharge current limit.

[c15] 15. The system set forth in claim 9, wherein, when drive performance is of higher priority to the user than engine start, the controller is further configured to:  
limit the electrical power of the generator during motor-ing to the maximum of the negative of the rated power limit of the generator, and a fourth operating condition of the hybrid powertrain system, when the fourth operating condition is less than zero;  
determine when a fifth operating condition of the hybrid powertrain system is less than zero, when the fourth op-

erating condition is equal to or greater than zero; limit the actual total power consumed by the auxiliary loads to the minimum auxiliary power requested, and limit the electrical power of the generator during motor-ing to the maximum of the negative of the rated power limit of the generator and the fifth operating condition, when the fifth operating condition is less than zero; and adjust an engine start strategy to provide earlier starting of the engine, when both the fourth and the fifth operating conditions are equal to or greater than zero, to provide over-discharge protection to the battery.

[c16] 16. The system set forth in claim 15, wherein the fourth operating condition includes the sum of the discharge power limit of the battery, the actual total power consumed by the auxiliary loads, the actual mechanical output power of the electric machine, and the actual power loss of the electric machine; and the fifth operating condition includes the sum of the discharge power limit of the battery, the minimum auxiliary power requested, the actual mechanical output power of the electric machine, and the actual power loss of the electric machine.

[c17] 17. The system set forth in claim 9, wherein the vehicle is configured as at least one of a series hybrid electric vehicle, and a series-parallel hybrid electric vehicle.

[c18] 18. A vehicle system controller (VSC) for controlling a hybrid powertrain system for an automotive vehicle operated by a user, the system having an engine, an electric machine that performs as a motor in one mode of operation and performs as a generator in another mode of operation, a battery connected to the electric machine, and a generator configured to receive mechanical power from the engine and to present electrical power to at least one of the electric machine and the battery, and at least one of the engine and the electric machine establish a power source for providing power to vehicle traction wheels, the vehicle system controller comprising: a regulator configured to receive a commanded engine speed signal and an actual engine speed signal, and present a transient state portion of a commanded generator output torque signal for regulation of speed of the engine;

a first memory including a model for over-charge protection of the battery that receives a voltage of the battery, a temperature of the battery, and a state of charge (SOC) of the battery, and presents a first charge current limit of the battery for over-voltage protection, a second charge current limit signal for over-current charge protection, and a battery charge power limit; and

a second memory including a model for under-voltage

protection for the battery that receives the voltage of the battery, the temperature of the battery, and the SOC of the battery, and presents a first discharge current limit of the battery for under-voltage protection, a second battery discharge current limit for over-current discharge protection, and a battery discharge power limit.

[c19] 19. The controller set forth in claim 18 wherein the controller is configured to:

determine a first power state of the hybrid powertrain system;

limit electrical power generated by the generator to the minimum of the rated power limit of the generator and the first power state, when the first power state is greater than zero; and

limit the electrical power generated by the generator to zero, and limit the power limit of the electric machine during generating to a first operating condition of the hybrid powertrain system, when the first power state is less than or equal to zero, to provide over-charge protection to the battery.

[c20] 20. The controller set forth in claim 19, wherein the first power state includes the sum of the actual mechanical output power of the electric machine, the actual power loss of the electric machine, the actual total power consumed by the auxiliary loads, and the battery charge

power limit; and

the first operating condition includes the negative of the sum of the actual power loss of the electric machine, the actual total power consumed by the auxiliary loads, and the battery charge power limit.

[c21] 21. The controller set forth in claim 20 wherein a battery charge current limit to provide both over-current and over-voltage protection to the battery is equal to the minimum of the rated battery charge current limit and a battery charge current limit predetermined by testing for avoiding battery over-voltage, and the battery charge power limit is equal to the minimum of the rated battery charge power limit and the product of battery voltage and the battery charge current limit.

[c22] 22. The controller set forth in claim 19, wherein, when engine start is of higher priority to the user than drive performance, the controller is further configured to: limit the power limit of the electric machine during motoring to the minimum of the rated power limit of the electric machine, and the negative of a second operating condition of the hybrid powertrain system, when the second operating condition is less than zero; determine when a third operating condition of the hybrid powertrain system is less than zero, when the second operating condition is equal to or greater than zero;

limit the auxiliary loads to the minimum power for maintaining the vehicle operation, and limit the power limit of the electric machine during motoring to the minimum of the rated power limit of the electric machine and the negative of the third operating condition, when the third operating condition is less than zero; and  
adjust an engine start strategy to provide earlier starting of the engine, when both the second and the third operating conditions are equal to or greater than zero, to provide over-discharge protection to the battery.

[c23] 23. The controller set forth in claim 22, wherein the second operating condition includes the sum of the discharge power limit of the battery, the actual total power consumed by the auxiliary loads, the negative of the actual electrical power output of the generator, and the actual power loss of the electric machine; and the third operating condition includes the sum of the discharge power limit of the battery, the minimum auxiliary power for maintaining vehicle operation, the negative of the actual electrical power output of the generator, and the actual power loss of the electric machine.

[c24] 24. The controller set forth in claim 23 wherein a battery discharge current limit to provide both over discharge current and under-voltage protection for the battery is equal to the maximum of the rated battery discharge

current limit and a battery discharge current limit predetermined by testing for avoiding battery under-voltage, and the discharge power limit of the battery to provide over-discharge protection to the battery equals the maximum of the rated battery discharge power limit and the product of the battery voltage and the battery discharge current limit.

- [c25] 25. The controller set forth in claim 19, wherein, when drive performance is of higher priority to the user than engine start, the controller is further configured to: limit the electrical power of the generator during motor-ing to the maximum of the negative of the rated power limit of the generator, and a fourth operating condition of the hybrid powertrain system, when the fourth operating condition is less than zero; determine when a fifth operating condition of the hybrid powertrain system is less than zero, when the fourth operating condition is equal to or greater than zero; limit the actual total power consumed by the auxiliary loads to the minimum auxiliary power requested, and limit the electrical power of the generator during motor-ing to the maximum of the negative of the rated power limit of the generator and the fifth operating condition, when the fifth operating condition is less than zero; and adjust an engine start strategy to provide earlier starting

of the engine, when both the fourth and the fifth operating conditions are equal to or greater than zero, to provide over-discharge protection to the battery.

- [c26] 26. The controller set forth in claim 25, wherein the fourth operating condition includes the sum of the discharge power limit of the battery, the actual total power consumed by the auxiliary loads, the actual mechanical output power of the electric machine, and the actual power loss of the electric machine; and the fifth operating condition includes the sum of the discharge power limit of the battery, the minimum auxiliary power requested, the actual mechanical output power of the electric machine, and the actual power loss of the electric machine.